USAARL Report No. 2004-16

Speech Intelligibility with Helicopter Noise: Tests of Three Helmet-Mounted Communication Systems (Reprint)

by John E. Ribera, Ben T. Mozo, and Barbara A. Murphy

Aircrew Protection Division

May 2004

Approved for public release, distribution unlimited.

USAARL

U.S. Army
Aeromedical Research
Laboratory

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), 8725 John J Kingman Road, Suite 0944, Fort Belvoir, Virginia 22060-6218. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about Laboratory reports.

Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
May 2004

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Speech Intelligibility With Helicopter Noise: Tests of Three Helmet-Mounted Communication Systems (Reprint)

5. FUNDING NUMBERS
PR: 878
TA: O
PE: 622787
WU: DA360347

6. AUTHOR(S)
John E. Ribera, Ben T. Mozo, and Barbara A. Murphy

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, AL 36362-0577

8. PERFORMING ORGANIZATION REPORT NUMBER
2004-16

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Material Command
504 Scott Street
Fort Detrick, MD 21702-5012

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Article was originally printed in Aviation, Space, and Environmental Medicine, Vol. 75, No. 2, February 2004

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Military aviator helmet communications systems are designed to enhance speech intelligibility (SI) in background noise and reduce exposure to harmful levels of noise. Some aviators, over the course of their aviation career, develop noise-induced hearing loss that may affect their ability to perform required tasks. New technology can improve SI in noise for aviators with normal hearing as well as those with hearing loss. SI in noise scores were obtained from 40 rotary-wing aviators (20 with normal hearing and 20 with hearing-loss waivers). There were three communications systems evaluated: a standard SPH-4B, an SPH-4B aviator helmet modified with communications earplug (CEP), and an SPH-4B modified with active noise reduction (ANR). Subjects' SI was better in noise with newer technologies than with the standard issue aviator helmet. A significant number of aviators on waivers for hearing loss performed within the range of their normal hearing counterparts when wearing the newer technology. The rank order of perceived speech clarity was 1) CEP, 2) ANR, and 3) unmodified SPH-4B. To insure optimum SI in noise for rotary-wing aviators, consideration should be given to retrofitting existing aviator helmets with new technology, and incorporating such advances in communication systems of the future. Review of standards for determining fitness to fly is needed.

14. SUBJECT TERMS
Speech intelligibility, noise, rotary wing helicopter, helmets, communications systems, hearing, hearing loss

15. NUMBER OF PAGES
5

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

Speech Intelligibility With Helicopter Noise: Tests of Three Helmet-Mounted Communication Systems

JOHN E. RIBERA, BEN T. MOZO, AND BARBARA A. MURPHY

RIBERA JE, MOZO BT, MURPHY BA. *Speech intelligibility with helicopter noise: tests of three helmet-mounted communication systems.* **Aviat Space Environ Med 2004; 75:132–7.**

Background: Military aviator helmet communications systems are designed to enhance speech intelligibility (SI) in background noise and reduce exposure to harmful levels of noise. Some aviators, over the course of their aviation career, develop noise-induced hearing loss that may affect their ability to perform required tasks. New technology can improve SI in noise for aviators with normal hearing as well as those with hearing loss. ***Methods:*** SI in noise scores were obtained from 40 rotary-wing aviators (20 with normal hearing and 20 with hearing-loss waivers). There were three communications systems evaluated: a standard SPH-4B, an SPH-4B aviator helmet modified with communications earplug (CEP), and an SPH-4B modified with active noise reduction (ANR). ***Results:*** Subjects' SI was better in noise with newer technologies than with the standard issue aviator helmet. A significant number of aviators on waivers for hearing loss performed within the range of their normal hearing counterparts when wearing the newer technology. The rank order of perceived speech clarity was 1) CEP, 2) ANR, and 3) unmodified SPH-4B. ***Conclusions:*** To insure optimum SI in noise for rotary-wing aviators, consideration should be given to retrofitting existing aviator helmets with new technology, and incorporating such advances in communication systems of the future. Review of standards for determining fitness to fly is needed.

Keywords: Speech intelligibility in noise, aviator helmet, fitness to fly.

NOISE LEVELS IN U.S. Army helicopters exceed safe limits in accordance with Department of Defense Instruction 6055.12 (5). The rotary-wing flying environment is noisy, and intercommunications systems introduce acoustic distortion. As a result, many aviators have a hearing loss. In some cases, the ability of the helmet alone to protect the hearing of the aviator is marginal. Using combination or double protection, by wearing earplugs in addition to the aviator helmet, can compound the problem, particularly in cases where intercommunications systems (ICS) are not capable of producing the speech levels needed to overcome the earplug sound attenuation (9).

Voice communications are critical to the successful completion of the aviator's mission. The aviator must be able to understand complex messages quickly and completely in order to maintain complete control of the aircraft and gain every advantage over opposing forces. Poor communications may compromise the mission and result in the loss of life and property. There is evidence that high noise levels, degraded communication signal, and sensorineural hearing loss combine to impair speech intelligibility (SI) (1). Those with hearing loss may be at especially increased risk for aircraft mishap due to degraded SI.

The noise spectrum within military helicopter crew compartments is predominantly low frequency with peak levels occurring near the blade passing frequency. Noise sources in addition to the blades include engines, blowers, transmissions, vibration, and turbulence caused by the movement of the helicopter through the atmosphere. Since helicopter noise levels normally exceed 85 dBA, hearing protection is required. Military aviator helmets, among other functions, address this safety issue by providing noise attenuation for the crewmembers. To facilitate internal communication, all aircrew on rotary-winged aircraft use electrically augmented communication systems for crew coordination.

The effectiveness of hearing protective devices with communication capability is generally determined via sound attenuation measures using standard laboratory techniques. Results from laboratory evaluations are subsequently applied through mathematical models to estimate the expected performance in a user's particular noise environment. This approach uses noise level values from measurements that were made in the operational environment to demonstrate the effectiveness of the hearing protector. New technology is now available that may enhance hearing in noise over communications systems currently in use in Army aviation. Comparison of existing and new technologies is a logical step in evaluating optimum listening conditions and hearing protection for aviators.

Factors Affecting SI

Hearing protector effectiveness may be compromised by any of several factors: improper fit for the individ-

From the U.S. Army Aeromedical Research Laboratory, Ft. Rucker, AL.

This manuscript was received for review in June 2003. It was revised in July and August 2003. It was accepted for publication in August 2003.

Address reprint requests to: John E. Ribera, Ph.D., Associate Professor, Utah State University, Department of Communicative Disorders and Deaf Education, 1000 Old Main Hill, Logan, UT 84322-1000; jribera@cc.usu.edu.

John Ribera is a retired U.S. Army officer and is currently on the faculty at Utah State University, Logan, UT.

ual, use of ancillary equipment such as eyeglasses or a chemical/biological protective mask that may compromise the interface of the hearing protective device with the subject, and inherently inadequate sound attenuation for the noise environment in which the protector is to be used (9). The primary factor affecting SI is the speech-to-noise ratio, which is directly related to sound attenuation of the hearing protector. A favorable speech-to-noise ratio is one where the target signal, in this case speech, is sufficiently elevated above the noise floor so as to permit adequate processing by the listener. The greater the speech-to-noise ratio, the more intelligible the message communicated.

SPH-4B Aviator Helmet

Army aviators wear the SPH-4 series helmet, or its replacement, the HGU-56/P. Both helmets have similar sound attenuation and frequency response characteristics. Functions of the SPH-4B helmet include protection of aircrew hearing while providing adequate auditory communications (7). Use of combination or double protection (helmet plus earplugs) is common among aviators as a means of providing additional in-flight hearing protection. However, it is believed that double protection can affect an aircrew member's ability to hear speech. For instance, the helmet earphone output must overcome the attenuation of the earplug in order to provide speech signals to the ear that are loud enough to be understood. At high levels of amplification, acoustic signal distortion can impact SI.

Communications Ear Plug (CEP)

The CEP falls into the category of new technology designed to enhance communication in noise, while providing hearing protection. The CEP was conceived, developed, and evaluated at the U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL. The CEP is a device that uses a miniature earphone transducer adapted to a foam earplug with a screw-on tip. The CEP fits into the ear canal and connects into the ICS of Army helicopters. A 2.5 mm diameter hole from the tip to the base of the earplug provides a path for sound generated by the transducer to enter the occluded portion of the ear canal. When the CEP is worn in combination with the flight helmet (also approved for the integrated helmet and display sight system), the attenuation of noise for all frequencies and the speech signal-to-noise ratio are improved (9).

Active Noise Reduction (ANR)

ANR is another approach for reducing noise under the helmet ear cup while increasing the speech-to-noise ratio. The theoretical basis for ANR has been in existence for several years. ANR is a closed-loop system that cancels unwanted noise by outputting into the ear cup a counterphased acoustic signal that cancels some of the noise that penetrates the ear cup. As implemented, the noise cancellation affects primarily the low frequencies up to 600 Hz (16).

Fitness To Fly

Army aviators are screened annually for hearing loss. Aviators with profound hearing loss affecting flight safety are medically terminated from aviation service. Those with mild to moderate hearing loss undergo a complete audiologic evaluation. Most aviators with high frequency hearing loss and binaural speech discrimination (word recognition) scores equal to or greater than 84% are returned to flying duties with a waiver. Interestingly, the conventional hearing tests used in the evaluation process for fitness to fly are conducted in quiet. Assessing an aviator's functional hearing in noisy environments may give a more accurate description of the aviator's auditory communication ability.

Purpose of the Study

The focus of this study was to compare SI in noise between aviators with an aeromedical waiver due to hearing loss and normal hearing aviators, each group wearing three communication/hearing-protection devices. The devices under investigation included the standard issue SPH-4B Army aviation helmet, the SPH-4B modified with CEP, and the SPH-4B modified with a prototype ANR system. Data for this study were collected in 1995–1996. At that time, SPH-4B helmets were widely used. SPH-4B helmets are being systematically replaced in active, reserve, and National Guard units by the HGU-56/P. As mentioned earlier, the attenuation and acoustic characteristics of both the SPH-4B and the HGU-56/P are similar. It was the opinion of the authors that the results of this study could be generalized to the newer HGU-56/P device and, therefore, should be published.

METHODS

SI

SI through a communications system may be measured using any of several methods. Generally, the listener is placed in a controlled environment that simulates the noise characteristics of that in which the device is eventually to be used. The listener is asked to transcribe words heard over the communications system. SI is recorded as the percent of words correctly transcribed. Speech material may be of varying lengths. However, monosyllabic word lists are commonly used.

Human Subjects

There were 40 male subjects (20 aviators with normal hearing, 20 aviators with waivers), ages 24–66, recruited from active duty Army aviators, Department of Army civilian aviators, and civilian contractors from local flight units at Fort Rucker, AL. Only male aviators were selected due to the limited number of female aviators near the test site. In addition, males were selected because they were representative of the population of Army and civilian aviators at the time of the study. The study protocol was approved in advance by the Scientific Review Committee, U.S. Army Aeromedical Research Laboratory at Fort Rucker, AL. Each sub-

TABLE I. CLASS II HEARING STANDARDS IN DB HL FOR ARMY AVIATORS.

Frequency (Hz)	500	1000	2000	3000	4000	6000
Better ear	25	25	25	35	65	75
Worse ear	25	35	35	45	65	75

ject provided written, informed consent before participating.

Subjects were screened by otoscopic examination, middle ear function test (tympanometry), and hearing health intake history. Selection criteria for the normal hearing aviators (control group) were limited to audiometric thresholds no greater than Army Class II hearing standards for aviators (2). Subjects in the waiver (experimental) group were defined as those aviators exhibiting a sensorineural hearing loss that exceeded Army Class II standards as presented in **Table I**, and who were on waivered status.

Audiometry

Behavioral audiometric thresholds were obtained pre- and postnoise exposure using a modified Houghson-Westlake descending method at 0.125, 0.250, 0.500, 1, 2, 3, 4, 6, and 8 KHz. Testing was conducted in a sound-treated booth by a certified audiologist using a GSI-10 audiometer (Grason-Stadler, Madison, WI).

Establishing Speech Presentation Levels

Speech signal levels were determined by measuring frequency responses for each of the three devices, analyzed into one-third octave band levels, at dBA and dB linear levels using a Fast Fourier Transform Analyzer (Model 2630, Tektronix® Inc., Beaverton, OR) (9). Prerecorded speech (W-22, 50-word lists) was presented through each device under test and measured in quiet. Word lists were presented in rapid succession while measuring the equivalent continuous sound level of the sound signal produced by the device under test. The results of this measurement were used to determine the attenuator settings required for the 85 dBA and 95 dBA speech presentation levels (9).

SI in Background Noise

Participants were trained in proper fitting techniques for each of the devices under investigation by a technician experienced in hearing protector fitting procedures. After training, participants were responsible for donning and doffing each helmet under test. The technician monitored the fit of each device and provided additional training as necessary.

A speech reception threshold level was determined for each device for each subject using a list of 36 W-1 spondaic words (11) prior to the SI test series. Speech reception threshold is defined as the level at which the listener achieves a 50% correct response (14). Speech materials used to determine SI consisted of four prerecorded lists (W-22) with four orderings of each list. The words were presented to the listener at a rate of 12 per minute. The recordings for all speech materials were commercially available products from Auditec® of St. Louis, MO. Each list consisted of 50 monosyllabic words. Monosyllabic words were chosen in order to tax the listener and to provide a highly sensitive measure of intelligibility for each device.

Subsequently, each participant was given an SI pretest to screen out subjects who had difficulty performing the SI task. Subjects were fully familiarized with the four word lists used in the SI measurements. The order of tests was randomized using a Latin squares design to minimize any learning effects (13). Subjects were then seated in a reverberant chamber using noise levels which simulated a UH-60 helicopter during cruise at 120 kn. Mozo and Murphy (9) described the details of the setup for this study. Overall levels of the noise were adjusted to 105 dBA (re 20 μPa).

Subjects were asked to listen to the words presented and record their answers on a numbered sheet. SI tests were scored as percent correct for each device and test condition. Total test time was approximately 5 h divided into two test sessions. There were six conditions for SI testing for each subject. The speech stimuli were presented at fixed levels of 85 dBA and 95 dBA for each of the three helmet configurations. The SI for constant speech level input of 85 dBA and 95 dBA was used to determine the relative merit of the devices at levels near the acceptable sound pressure level input limit. These levels were derived from research by Camp, Mozo, and Patterson (3). Their research revealed that CH-47 Chinook helicopter noise under SPH-4 helmets averaged 85 dBA (ICS off) and 95 dBA (ICS on). Noise levels in a CH-47 helicopter at some locations within the aircraft exceed those of the UH-60. The rationale for using the data from Camp, Mozo, and Patterson was to provide a worst-case scenario. Given the method for deriving speech presentation levels for this study, it might prove more realistic to think of these levels in terms of time-weighted average. Time-weighted average is a calculation of variable noise exposure doses over a given time to which an individual is subjected compared with the allowable duration and level of noise for that period of time. In this study, subjects were not exposed to a steady-state level of speech stimulus of 95 dBA.

RESULTS

Audiometry

Postexposure audiometric configurations for the two test groups are presented in **Table II**. Mean thresholds and standard deviations for both groups reflect little difference between ears (pre- and postnoise exposure), therefore, right and left ear data were collapsed. Normal hearing aviator thresholds averaged below 20 dB

TABLE II. MEAN POST-NOISE/SPEECH EXPOSURE AUDIOMETRIC DATA IN DBHL.

	Frequency (Hz)								
	125	250	500	1000	2000	3000	4000	6000	8000
Normal	3	3	4	5	4	12	19	19	19
Waivered	7	8	11	13	18	46	60	63	60

TABLE III. PERCENTAGE OF WAIVERED AVIATORS WITH SPEECH INTELLIGIBILITY SCORES FALLING AT OR ABOVE THE LOWER CI_{95} SCORES FOR NORMAL HEARING AVIATORS.

	85 dBA	95 dBA
ANR	45	45
CEP	60	50
SPH-4B	5	40

HL across all test frequencies. Waivered aviator audiograms revealed bilaterally symmetrical mild-to-moderate high frequency sensorineural hearing losses. Standard deviations among the waivered aviators were greater than for the normal hearing aviators across all frequencies. Test-retest results (pre- and postspeech and noise exposure) were within the conventional criteria of ± 5 dB (15). These findings confirm that no hearing loss occurred from exposure to the levels of speech and/or noise generated for the study. ANOVA data analysis revealed: (a) no significant differences between pre- and postexposure tests, (b) a difference between groups, and (c) a difference across frequencies. Questionnaire responses from subjects attributed hearing losses primarily to noise exposure (aircraft, recreational, other military assignments in noise, etc.).

SI Results

Data for the two presentation levels of speech through the three devices were subjected to a repeated measures ANOVA calculation using BMDP v. 4.0 (BMDP Statistical Software, Inc., Los Angeles, CA). There was a statistical significance for the following main effects: group [$F(1,38) = 9.20$, $p = 0.0043$], speech level [$F(3,114) = 139.77$, $p < 0.0001$], device [$F(2,76) = 35.76$, $p < 0.0001$], and device by speech level [$F(6,228)$ 38.50, $p < 0.0001$]. There were significant contrasts between all test devices at 85 dBA: ANR vs. CEP [$F(1,38) = 9.73$, $p = 0.0034$], ANR vs. SPH-4B [$F(1,38) = 133.15$, $p < 0.0001$], and CEP vs. SPH-4B [$F(1,38) = 182.07$, $p < 0.0001$]. At 95 dBA there was no significance statistical contrast between ANR and CEP devices. However, significant contrasts were observed at the same speech level for ANR vs. SPH-4B [$F(1,38) = 26.32$, $p < 0.0001$] and CEP vs. SPH-4B [$F(1,38)$ 88.19, $p < 0.0001$].

In order to better understand what impact the helmets equipped with newer technology had on performance, the mean of all normal subjects' SI scores, as well as the 95th percent confidence interval (CI_{95}), were computed. The lower CI_{95} border (floor) was used as a benchmark to delineate the bottom acceptable range. Waivered aviator scores were compared with the benchmark. **Table III** reveals what percentage of waivered aviators performed within the normal range based on speech level and device worn.

DISCUSSION

General trends from ANOVA and Table III revealed the following: 1) SI scores at all levels were higher for normals than for waivered aviators no matter the device worn; 2) the higher the level of the speech signal, the greater the SI score for both groups, irrespective of the device worn; 3) when ANR and CEP were worn, both groups obtained better scores than when wearing the unmodified SPH-4B; and 4) although not significantly different, the best scores for both groups at 85 dBA and 95 dBA were attained when wearing the CEP. These overall findings also suggest that aviators equipped with more advanced communications systems could be expected to experience less stress during flight, have less difficulty hearing in noise, and reduce the likelihood of an accident/mishap as a result of a degraded acoustical signal. There is one other implied benefit from listening at lower levels, namely hearing conservation. The less energy directed at the eardrum, the less likely the listener is to ultimately suffer from a noise-induced hearing loss.

Camp, Mozo, and Patterson (3) found that aviators, as one would predict, tend to turn the volume control (VC) on the ICS box to a comfortable listening level. However, they also found that the level selected actually yielded lower SI scores than if the VC were set lower. In other words, lower, not higher settings, improve SI in noise, and counterintuitively, aviators are not the best judges of optimum intelligibility. The Camp, Mozo, and Patterson (3) findings served as the basis in this study for speech input levels that were fixed and not self-adjusted. The results of the current study suggest that aviators would be more likely to turn the VC on the ICS down if their helmets were equipped with ANR or CEP technology. This predicted behavior has been informally confirmed at Fort Rucker, AL, through anecdotal accounts of aviators wearing helmets modified with the CEP while flying.

In order to determine the functional impact of each device on the SI of waivered aviators, the lower CI_{95} for normals was computed for each of the devices at the two speech presentation levels (85 dBA and 95 dBA). The SI scores of each waivered aviator were compared to see how many, if any, of the scores from the experimental group fell into the normal range of performance as a result of wearing the devices under investigation.

Table III reveals an unexpected benefit from the newer technology, namely that when ANR or CEP were installed into standard aviator helmets, the scores from a significant percentage of waivered aviators fell within the range of normal performance. For example, at 85 dBA speech level, when wearing the CEP system, 60% of waivered aviators performed within the range of their normal hearing counterparts on the SI test. This finding has implications for future development of aviation communication systems as well as fitness to fly standards.

When asked at the conclusion of the study if there was any noticeable difference between the three test devices in terms of speech clarity, 95% of the normals and 90% of the waivered subjects answered yes. The follow-up portion of the exit survey asked respondents to rank order the devices, once again in terms of speech clarity (1 = clearest; 3 = least clear). Of subjects queried, 75% (15 normal and 15 waivered) preferred listening through the CEP. ANR was preferred by 15%, followed by SPH-4B by the remaining 10%.

TABLE IV. PERCENT OF AVIATORS IN THIS STUDY THAT FELL INTO THE "EXCEPTIONALLY-HIGH TO NORMAL" CATEGORIES RE MILITARY STANDARD 1472D BY GROUP.

	85 dBA		95 dBA	
	Normal	Waivered	Normal	Waivered
ANR	55	40	90	80
CEP	90	65	95	85
SPH-4B	0	5	70	40

Military Standard 1472D (8) indicates that monosyllabic word tests should be used to assess SI in communications systems when a high degree of sensitivity and accuracy are needed. It would seem tenable, therefore, to consider where the SI scores for both subject groups in this study fell in relation to these criteria. The categories of "exceptionally high" and "normal" intelligibility as defined in Military Standard 1472D (8) have been arbitrarily grouped together in **Table IV**.

The findings from Table IV reveal a pattern of better performance when ANR and CEP systems deliver the speech signal than when speech is presented through the unmodified SPH-4B system. For instance, at 85 dBA, when the CEP was worn, 65% of waivered aviators and 90% of normals fell within the exceptionally high-normal category. Whereas at the same level of speech signal, when the unmodified SPH-4B was worn, only 5% of waivered and none of the normal hearing aviators fell into the exceptionally high-normal category. It may seem counterintuitive that normals would perform worse than those with a waiver for hearing loss. However, 5% in this small sample represents only one subject and, therefore, is probably just a variation due to chance. These findings confirm earlier observations and provide compelling evidence to support retro-fitting of existing Army aviator helmets with CEP or ANR technology.

CONCLUSIONS

The results of this study show that ANR and CEP technology enhance voice communications for the aviator in noise when compared with the basic issue SPH-4B helmet. In summary: 1) normals scored higher than waivered subjects on all devices; 2) both ANR and CEP communications devices improved SI in both waivered and normal groups when compared with the unmodified SPH-4B; 3) many waivered aviators were able to perform within the normal range of performance in the SI tests when new technology was used; 4) at low levels of speech input both ANR and CEP outperformed the standard helmet when speech was presented at 95 dBA; 5) the change in SI scores was less dramatic for the CEP between 85 dBA and 95 dBA than for ANR or the unmodified SPH-4B (probably because the CEP performance had already reached asymptote at 85 dBA); and 6) the CEP was perceived to have the greatest clarity of speech by a ratio of 3:1 over ANR and the unmodified SPH-4B. Due to similarities in attenuation and communications system characteristics for the SPH-4B and HGU-56/P, findings from this study suggest both helmets can be significantly improved by incorporating ANR or CEP technology.

Based on the results of this study, a large proportion of waivered aviators can be expected to understand speech in background noise as well as their normal hearing counterparts, provided their communications system is modified with ANR or CEP technology. The results of this study are compelling and should serve as impetus for changes in the existing communications system configuration and future aviator helmet design in the rotary-wing environment. Proactive decision-makers may wish to compare the CEP and ANR. Issues that might be considered are: attenuation, effects of ancillary equipment (eyeglasses, protective mask), perceived background noise, VC setting, comfort, weight, impact protection, compatibility with existing aircraft communications systems, cost, installation, power requirements, and aircraft modifications when contemplating upgrading systems. There are significant differences that merit a detailed comparison (10).

While this study did not determine the best criteria for determining fitness to fly, it has highlighted the need to do so. It is worth noting that the SI in noise of a significant number of waivered aviators can be improved with new technology, resulting in near-normal performance. This may be an appropriate time to revisit fitness to fly standards, particularly the criteria for determining waivered status. It is conceivable that in the future, flight surgeons will place aviators with a hearing loss on waivered status on condition that their helmets are equipped with ANR or CEP technology.

The point at which SI degradation affects flight safety has not been studied. Therefore, research is needed to assist the aviation medical community in developing criteria to determine fitness to fly for both aviators with normal hearing and those with hearing loss. It is foreseeable that speech in noise tests such as the Hearing In Noise Test (12), SPeech Recognition In Noise Test (4), or the Speech In Noise Test (6), along with other conventional tests, could be used in the future as a test battery to assist flight surgeons in determining the eligibility of aviators to continue flying.

ACKNOWLEDGMENTS

A special thanks is in order to Dr. Lynn Caldwell for statistical analysis of the data.

The opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the U.S. Army and/or the Department of Defense.

REFERENCES

1. Able SM, Alberti PW, Haythornwaite C, et al. Speech intelligibility in noise with and without ear protectors. In: Alberti PW, ed. Personal hearing protection in industry. New York: Raven Press; 1980:371–86.
2. Army Regulation 40–501. Medical services standards of medical fitness. Washington, DC: Headquarters, Dept. of the Army; 2002. Available online at http://www.usapa.army.mil.
3. Camp R, Mozo B, Patterson J. An investigation of aircraft voice communications systems as a source of insidious long-term acoustic hazards. In: Whitcomb MA, ed. Proceedings of the North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development; November 1975; Soesterberg Airbase, Netherlands.
4. Cord M, Walden B, Atack R. Speech recognition in noise test (SPRINT) for H-3 profile. Instructions. Washington, DC: Walter Reed Army Medical Center; 1993.

5. Department of Defense. Hearing conservation program. Washington DC: Department of Defense; DOD Instruction 1991:6055.12.
6. Etymotic Research. The SIN test [CD]. Elk Grove Village, IL: Etymotic Research; 1993.
7. Military specification MIL-H-43925, helmet, flyer's protective, SPH-4. Natick, MA: USARIEM; 1988. Available online at http://dodssp.daps.mil.
8. Military standard 1472D. Human engineering design criteria for military systems, equipment and facilities. Redstone Arsenal, AL: U.S. Army Missile Command; 1989. Available online at http://dodssp.daps.mil.
9. Mozo B, Murphy B. The assessment of sound attenuation and speech intelligibility of selected active noise reduction devices and the communications earplug when used with the HGU-56/P aviator helmet. Fort Rucker, AL: US Army Aeromedical Research Laboratory; 1997. Report No: 97-08.
10. Mozo B, Ribera J. Communications earplug: a logical choice for voice communications in aircraft [reprint]. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory, 1998.
11. Newby HA. Audiology. 3rd ed. New York: Meredith Corporation, 1972:393–4.
12. Nilsson M, Soli S, Sullivan J. Development of the hearing in noise test for the measurement of speech reception thresholds in quiet and noise. J Acoust Soc Am 1993; 95:1085–99.
13. Vajda S. The mathematics of experimental design: Incomplete block designs and latin squares. New York: Hafner Publishing Company; 1967:22–53.
14. Van Tassel DJ, Yanz JL. Speech recognition threshold in noise: Effects of hearing loss, frequency response and speech materials. J Speech Hear Res 1987; 30:377–86.
15. Ventry I, Chaiklin J, Dixon R. Hearing measurements: A book of readings. New York: Meredith Corporation, 1971:100–8.
16. White Paper. Active noise cancellation for armored vehicle intercom systems. Framingham, MA: Bose Corporation; 1990.